Computed tomography morphometric analysis of C2 translaminar screw fixation of Wright's technique and a modified technique in the pediatric cervical spine

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Abstract

Purpose To establish reference data on the dimensions of C2 lamina to guide the use of translaminar screws with Wright's technique and a modified technique for pediatric patients in different age groups.

Methods 113 pediatric patients were divided into six age groups, and their cervical vertebrae were studied on CT scans. Lamina height, width, length and screw angle were measured. Statistical analysis was performed using Student *t* tests, Pearson's correlation and linear regression analysis. **Results** Mean lamina height was 10.95 ± 2.81 mm, and mean width was 6.01 ± 0.90 mm. For Wright's technique, mean lamina length was 30.65 ± 3 mm, and the screw angle was $56.02^\circ \pm 3.62^\circ$. For the modified technique, mean lamina length was 22.07 ± 2.38 mm, and the screw angle was $67.40^\circ \pm 3.39^\circ$. 95.6 % (108/113) of the children could insert a screw into the lamina (lamina width ≥ 4.5 mm), 72.6 % (82/113) could accept bilateral translaminar screws (lamina width ≥ 4.5 mm and lamina height ≥ 9 mm).

Conclusion Our investigation provides insight into the anatomy of C2 lamina in six pediatric age groups. Compared to adults, the benefits of C2 translaminar screws fixation are more obvious in the pediatric spine which has a large C2 lamina. Compared to Wright's technique, the

modified technique should insert a screw with bigger insert angle and shorter screw length.

Keywords Pediatric spine · Computed tomography · Translaminar screw · Modified technique

Introduction

Treatment of upper cervical spinal instability in children usually is conservative (e.g., halo orthosis). However, available data are insufficient to determine if conservative therapy is rigid enough to immobilize the atlantoaxial complex, and halo orthosis can lead to many complications [1, 2]. Thus, in some cases, the ideal therapy has been surgical fixation [3–5]. Many surgical stabilization techniques have been used for fixation of children's atlantoaxial complex. Posterior wiring methods [6, 7] are technically simple and safe procedures but have high failure rates in fusion [8]. More rigid fixation techniques such as the transarticular C1–C2 screw technique [9] and the C2 pedicle screw technique [10] provide high fusion rates but could injure the vertebral artery [11, 12].

A new technique using C2 translaminar screws pioneered by Wright in 2004 [13], has gained popularity due to the large size of the C2 lamina, the rigid fixation of the axis, and the reduced risk of injury to the vertebral artery. It has been universally used to treat upper cervical spinal instability in children [3–5]. The Wright technique, however, has some disadvantages, including partial dorsal lamina breach, violation of the spinal canal, early hardware fracture, and difficulty in placement of a bone graft [14]. To address these issues, Jea et al. [15] slightly modified Wright's technique to include an “exit” window at the facet-lamina junction; the “exit” window allow direct

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visualization of the tip of the screw exiting the outer cortices of the lamina before leaving the operating room.

This study was designed to evaluate the dimensions of the C2 lamina of Chinese children to determine the feasibility of inserting screws into the laminae using Wright's technique and the modified technique.

Materials and methods

Clinical materials

The research was performed following Declaration of Helsinki principles and was approved by the institutional review board. We analyzed the cervical spine computed tomography (CT) scans of 61 Chinese boys and 52 girls treated in the Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical College between January 2004 and October 2012. Patients were excluded if they had a spinal abnormality such as a congenital deformity, trauma, or primary or secondary tumors. These children, ages 1–18 years old, were chosen through a stratified random sampling method and classified into six age groups (Table 1): 1–3 years (group 1, 13 patients), 4–6 years (group 2, 19 patients), 7–9 years (group 3, 17 patients), 10–12 years (group 4, 19 patients), 13–15 years (group 5, 18 patients), and 16–18 years (group 6, 27 patients).

Measurement methods

All CT images of each child were taken using a General Electric CT scanner (Philips Secura 16-slice, Philips Medical Systems, Eindhoven, the Netherlands). The scan parameters were: 120 kV, 180 MA, 512×512 matrix, slice thickness 2 mm, and pitch 1.0. Laminar height (LH), laminar width (LW), laminar length (LL), and screw angle (SA) were measured as previously described [16–18] and analyzed for screw placement with Wright's technique or the modified technique (Fig. 1). The LH of the axis was measured bilaterally in the parasagittal plane. The smallest value was recorded for analysis because it was the limiting

Fig. 1 The Wright's technique (a) and a modified technique (b)

factor in screw placement. The LW of the axis was measured bilaterally on all CTs at the isthmus, or the thinnest part of the lamina in the axial CT plane. Lamina length for screw placement was measured in two ways (Fig. 2), and the maximum LL was acquired. The SA for Wright's technique was traced for both sides, with one of the lines inside the C2 lamina parallel to the cortices of this lamina and another passing through the spinous process and odontoid process, dividing the vertebrae into two hemi-vertebrae. For the modified technique (MSA), one of the lines passed through the "entry" and "exit" windows and another passed through the spinous process and odontoid process, dividing the vertebrae into two hemi-vertebrae (Fig. 2). All measurements were rounded to the nearest 0.01 mm and were obtained using a picture archiving and communication system (PACS), an electronic and, ideally, filmless information system for storing, acquiring, transporting, and electronically displaying medical images.

Statistical analysis was performed using SPSS (SPSS Inc.) package software, and graphical representation of our data was created using an Excel spreadsheet (Microsoft Corp., Redmond, WA). For each group, mean values and corresponding standard deviations were calculated. An independent *t* test was used to test the difference between boys and girls in the different age groups. A paired sample *t* test was carried out for length and SA comparison between Wright's technique and the modified technique. Pearson's correlation coefficient was used to establish the correlation between age and other index. Linear regression analysis was used to estimate the growth rate of C2 lamina. A *P* value of <0.05 was selected to represent statistical significance.

Table 1 Summary of group design

Group	Age (years)	Male	Female	All
1	1–3	7	6	13
2	4–6	11	8	19
3	7–9	9	8	17
4	10–12	11	8	19
5	13–15	10	8	18
6	16–18	13	14	27

Results

The measurements of LH, LW, LL, and SA are presented in Table 2 and described here.

Laminar height

Mean values and standard deviations for the LH of each group are presented in Table 2. Mean LH for all patients

Fig. 2 Measurement of the pediatric cervical spine. **a** Axial CT scan showing the laminar width (LW), laminar length (LL, assuming the Wright's technique), screw angle (SA, assuming the Wright's technique); **b** axial CT scan showing the laminar length (MLL,

assuming the modified technique), screw angle (MSA, assuming the modified technique); **c** parasagittal reconstruction of CT scan showing the laminar height (LH)

was 10.95 ± 2.81 mm (range 5.98–16.59 mm). A total of 63.7 % (72/113) had an LH ≥ 10 mm; 72.6 % (82/113) had an LH ≥ 9 mm; and 78.0 % (87/113) had a LH ≥ 8 mm. There were no significant differences between boys and girls in any age group ($P > 0.05$). LH appeared to correlate well with age ($R = 0.895$, $P < 0.001$).

Laminar width

Mean values and standard deviations for the LW of each group are presented in Table 2. Mean LW for all patients was 6.01 ± 0.90 mm (range 3.77–8.22 mm). A total of 51.3 % (58/113) had an LW ≥ 6 mm; 81.4 % (92/113) had an LW ≥ 5 mm; and 99.1 % (112/113) had an LW ≥ 4 mm. There were no significant differences between boys and girls in any age group ($P > 0.05$). LW appeared to correlate well with age ($R = 0.688$, $P < 0.001$).

Laminar length

Mean values and standard deviations for LL and MLL of each group are presented in Table 2. Mean laminar length (using Wright's technique) for all patients was 30.65 ± 3 mm (range 21.43–38.27 mm). Except in group 3 ($P = 0.031$), there were no significant differences

between boys and girls in any age group ($P > 0.05$). LL (using Wright's technique) appeared to correlate well with age ($R = 0.724$, $P < 0.001$).

Mean laminar length (using the modified technique) for all patients was 22.07 ± 2.38 mm (range 15.78–27.00 mm). Except in group 3 ($P = 0.038$), there were no significant differences between boys and girls in any age group ($P > 0.05$). MLL (using the modified technique) appeared to correlate well with age ($r = 0.321$, $P = 0.001$). Significant differences in laminar length were noted with respect to LL and MLL using a paired sample *t* test ($P < 0.001$).

Screw angle

Mean values and standard deviations for SA and MSA of each group are presented in Table 2. Mean screw angle (using Wright's technique) for all patients was $56.02^\circ \pm 3.62^\circ$ (range 44.89°–64.41°). There were no significant differences between boys and girls in any age group ($P > 0.05$). SA appeared to be associated with aspects of age ($R = -0.284$, $P < 0.001$).

Mean screw angle (using the modified technique) for all patients was $67.40^\circ \pm 3.39^\circ$ (range 56.60°–76.15°). Except in group 2 ($P = 0.045$), there were no significant

Table 2 Height (mm), width (mm), length (mm) and angle (°) of C2, mean $\pm$ SD

Age (years)	LH (mm)	LW (mm)	LL (mm)	MLL (mm)	SA (°)	MSA (°)
1–3 Group 1						
F	6.84 $\pm$ 0.26	5.00 $\pm$ 0.37	25.82 $\pm$ 2.21	21.57 $\pm$ 2.36	54.11 $\pm$ 7.52	67.63 $\pm$ 1.80
M	6.75 $\pm$ 0.43	4.55 $\pm$ 0.39	23.76 $\pm$ 1.50	18.98 $\pm$ 2.51	59.19 $\pm$ 4.32	68.11 $\pm$ 1.92
A	6.79 $\pm$ 0.35	4.75 $\pm$ 0.43	24.71 $\pm$ 2.07	20.18 $\pm$ 2.69	56.85 $\pm$ 6.32	67.89 $\pm$ 1.81
4–6 Group 2						
F	8.11 $\pm$ 1.04	5.26 $\pm$ 0.40	28.25 $\pm$ 1.72	21.90 $\pm$ 0.86	57.30 $\pm$ 1.50	64.81 $\pm$ 1.88
M	7.91 $\pm$ 1.19	5.21 $\pm$ 0.51	29.15 $\pm$ 1.76	21.55 $\pm$ 2.21	56.91 $\pm$ 2.66*	67.50 $\pm$ 3.10*
A	7.99 $\pm$ 1.10	5.23 $\pm$ 0.46	28.77 $\pm$ 1.75	21.70 $\pm$ 1.68	57.08 $\pm$ 2.20	66.36 $\pm$ 2.93
7–9 Group 3						
F	9.64 $\pm$ 2.68	6.02 $\pm$ 0.61	27.86 $\pm$ 1.30	19.75 $\pm$ 1.46	58.10 $\pm$ 1.89	69.69 $\pm$ 3.31
M	10.41 $\pm$ 2.27	6.01 $\pm$ 0.89	30.63 $\pm$ 2.86*	22.10 $\pm$ 2.43*	56.55 $\pm$ 2.62	67.22 $\pm$ 3.97
A	10.09 $\pm$ 2.40	6.02 $\pm$ 0.77	29.48 $\pm$ 2.68	21.13 $\pm$ 2.35	57.18 $\pm$ 2.41	68.24 $\pm$ 3.81
10–12 Group 4						
F	11.96 $\pm$ 1.39	6.67 $\pm$ 0.33	31.34 $\pm$ 2.30	22.98 $\pm$ 1.64	57.34 $\pm$ 2.09	68.69 $\pm$ 1.82
M	11.74 $\pm$ 1.03	6.26 $\pm$ 0.72	31.89 $\pm$ 2.55	23.41 $\pm$ 2.56	56.64 $\pm$ 2.22	68.93 $\pm$ 2.95
A	11.83 $\pm$ 1.16	6.43 $\pm$ 0.61	31.66 $\pm$ 2.40	23.23 $\pm$ 2.18	56.93 $\pm$ 2.13	68.83 $\pm$ 2.48
13–15 Group 5						
F	12.56 $\pm$ 1.29	6.04 $\pm$ 0.42	32.79 $\pm$ 3.65	22.92 $\pm$ 2.01	53.76 $\pm$ 3.66	64.84 $\pm$ 4.16
M	12.74 $\pm$ 1.13	6.29 $\pm$ 0.76	32.80 $\pm$ 3.62	22.62 $\pm$ 2.82	53.24 $\pm$ 3.43	66.38 $\pm$ 3.99
A	12.67 $\pm$ 1.15	6.21 $\pm$ 0.66	32.80 $\pm$ 3.52	22.72 $\pm$ 2.52	53.42 $\pm$ 3.41	65.86 $\pm$ 3.99
16–18 Group 6						
F	13.52 $\pm$ 1.18	6.62 $\pm$ 0.58	33.01 $\pm$ 2.31	22.14 $\pm$ 2.00	54.11 $\pm$ 4.02	66.97 $\pm$ 3.90
M	14.01 $\pm$ 1.01	6.82 $\pm$ 0.68	33.74 $\pm$ 2.46	22.86 $\pm$ 2.13	56.05 $\pm$ 2.98	67.64 $\pm$ 3.72
A	13.81 $\pm$ 1.09	6.74 $\pm$ 0.64	33.45 $\pm$ 2.38	22.56 $\pm$ 2.07	55.26 $\pm$ 3.51	67.37 $\pm$ 3.74

F female, M male, A all patients, LH laminar height, LW laminar width, LL laminar length (assuming the Wright's technique), MLL laminar length (assuming the modified technique), SA screw angle (assuming the Wright's technique), MSA screw angle (assuming the modified technique)

* $P > 0.05$

differences between boys and girls in any age group ($P > 0.05$). Age did not appear to correlate with MSA ($P > 0.05$). Significant differences were noted with respect to SA and MSA using a paired sample t test (mean D -value was $11.22^\circ \pm 4.26^\circ$) ($P < 0.001$).

Growth rates of C2

Using linear regression models, we estimated the growth rates of C2 (LH, LW, and LL). The growth rate of LH was 0.481 mm/year, and the growth rate of LW was estimated to be 0.118 mm/year, while the growth rate of mean LL was estimated to be 0.514 mm/year (Fig. 3).

Discussion

A new technique using a C2 translaminar screw pioneered by Wright [13] in 2004 has gained popularity due to the large size of the C2 lamina, rigid fixation of the axis, and

reduced risk of injury to the vertebral artery. Placement of the laminar screw does not depend on the anatomy of the pedicle, pars, or vertebral foramen or require intraoperative neuronavigation or fluoroscopy. In 2006, Leonard and Wright [5] first reported on three children (one was 3 years old and two were 16 years old) with os odontoideum. Using bilateral crossing C-2 translaminar screws, all three patients received successful rigid atlantoaxial fixation with no complications. In another case, Fulkerson et al. [4] reported on two younger children (18 and 21 months old) in which a C2 translaminar screw was successfully and safely used.

To apply this technique more broadly in children, evaluation of the pediatric cervical spine anatomy of different age groups is very important. Chern et al. [16] investigated the cervical vertebrae of 69 pediatric patients on CT scans and measured LH and LW. According to the criteria ($LH \geq 9$ mm and $LW \geq 4.5$ mm), they found that the anatomy in 30.4 % of patients younger than 16 years could accommodate bilateral C-2 translaminar screws [16].

Fig. 3 Graph demonstrating laminar height (a), width (b) and length (c) against age at C2. A trend toward increase in height and length with increase in patient age was observed. In contrast, the laminar width changed minimally in the studied ages

Although this study established anatomical guidelines to allow accurate and safe screw selection and insertion, they did not describe the length and insertion angle for an optimal trajectory. In addition, two age groups were not sufficient for 69 pediatric patients who from 1.5 to 16 years old in this study. Cristante et al. [19] measured the angle, length, and thickness of 75 pediatric patients' C2 lamina and found that a base value of 45° for the spinolaminar angle can be adopted as a reference for insertion of screws into the C2 lamina. However, in this study, the age range

Fig. 4 Graph showing the distribution of patients whose anatomy as able to accept bilateral translaminal screws at the C2 level. 72.6 % (82/113) of patients the anatomy could accept bilateral translaminal screws

Fig. 5 Graph showing the screw angle (a) and laminar length (b) for Wright's technique and the modified technique presented statistically significant differences in all age groups. $**P < 0.001$

was only 2–10 years, and there were only two age groups to investigate age-related differences in pediatric lamina like previous work. In our study, 113 Chinese children

1–18 years old were classified into six age groups (Table 1). We measured LH and LW to investigate the limitations of this technique in the Chinese pediatric population, and investigated screw angle and length (using Wright's technique and the modified technique) to guide screw selection and optimal trajectory for these two techniques.

In this study, statistically significant age-related differences were noted in LH and LL (Fig. 3). However, LW changes little with age. Mean LL for all patients was 30.65 ± 3 mm (range 21.43–38.27 mm), so the LL was long enough to allow screw insertion. Assuming a 4.5-mm tolerance for each screw [20, 21], only five children did not have sufficient LW to allow screw insertion, so 95.6 % (108/113) had sufficient LW. Assuming that the minimum LH for bilateral screw placement is 9 mm, the anatomy in 72.6 % (82/113) of the children could accommodate bilateral translaminar screws. We demonstrated that the anatomy of children in the Groups 4–6 could safely accommodate placement of bilateral translaminar screws (Fig. 4), which means that patients older than 10 years can safely accommodate laminar and bilateral translaminar screws. These data differ from those of previous studies [16], which found that the anatomy of 30.4 % of children 1.5–16 years old and 45.9 % of children older than 8 years could accept bilateral translaminar screws. These differences may be due to measurement error or differences between races and the inclusion of a 16- to 18-year-old age group in our study.

Measurement of laminar length and screw angle for Wright's technique and the modified technique demonstrated statistically significant differences in all age groups (Fig. 5). Using the modified technique, we found the screw length was shorter (about 8.59 ± 2.51 mm) than the screw used in Wright's technique and had a larger screw angle ($11.22^\circ \pm 4.26^\circ$). This means that, when we insert a screw into the C2 lamina using the modified technique, we should choose a shorter screw, and the trajectory of C2 laminar screw placement requires a larger insertion angle than parallel to the down slope of the dorsal aspect of the contralateral lamina.

Conclusion

Fixation of C2 by means of laminar screws has recently emerged as a new technique for surgical fusion. Our investigation provides insight into the anatomy of C2 lamina in six pediatric age groups, and shows C2 translaminar screws fixation could be safely used in a majority of Chinese pediatric patients. Compared to Wright's technique, the modified technique should insert a screw with bigger insert angle and shorter screw length.

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Conflict of interest None of the authors has any potential conflict of interest.

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